

# **Vulnerability of Transportation Systems to Sea Level Rise**

## **Preliminary Assessment**



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## **Introduction**

Over the last few years, scientists have confirmed predictions of climate change and the potential impacts of its various scenarios. In particular, scenarios such as sea level rise, temperature rise, and variability of precipitation could have significant effects on California's transportation infrastructure with serious implications to safety and the State's economy. Consistent with the Governor's landmark Global Warming initiatives which includes the Global Warming Solutions Act, Assembly Bill 32, and Executive Order (EO) S-13-08, the Business, Transportation and Housing Agency (BTH) and the California Department of Transportation (Department) are approaching and managing climate risks by developing measures to reduce greenhouse gas (GHG) emissions from transportation. Through adaptation strategies, the Department is looking at ways to minimize the anticipated impacts of climate change on essential transportation infrastructure. This is with the overall goal of ensuring public safety, transportation system efficiency, and continued economic vitality of the State. The Department has taken decisive actions in support of the State's climate change objectives and toward reaching GHG emission reduction targets by the year 2020. At the same time, the Department is developing a climate change adaptation report to manage risks and challenges the State transportation infrastructure could face from unavoidable climate changes.

## **Purpose of the Report**

In response to the Governor's EO S-13-08, BTH and the Department prepared this preliminary assessment of the State's transportation systems' vulnerability to sea level rise. In addition, a more comprehensive climate change adaptation report is being developed that will be available by June 2009, as required by EO S-13-08. The adaptation report will include an updated vulnerability assessment. In addition, the California Resources Agency is in the process of retaining the National Academy of Sciences to develop a range of sea level rise scenarios for California for the years 2030, 2050, and 2100. Meanwhile, the underlying assumption for this preliminary assessment is that by 2100, California could experience a 55-inch rise in sea level. Climate scientists have predicted a number of climate change scenarios with a magnitude and probability of occurrences in California during this century. Several of these anticipated climate change scenarios are of particular significance to the transportation system. This preliminary assessment specifically addresses sea level rise and storm surge. It has been determined that the probability of occurrence of sea level rise and storm surge has a virtual certainty greater than 99 percent.

## **Potential Impacts of Sea Level Rise and Storm Surge on the Transportation System**

California is one of the most diverse regions—ecologically, geographically, and culturally—in the world. Sea level rise and storm surge could gradually modify the characteristics of a sizeable portion of the State with certain implications for California's vast transportation network. California has over 1,100 miles of coastline and 1,000 miles of enclosed bay with variable regional microclimate environments that are most vulnerable to effects of sea level rise and storm surges. According to the 2000 Census, 14 percent of California's population and 16 percent of residential development are located near shoreline. Nearly 31 million people lived in coastal counties in 2003, and the number continues to grow. These low-lying coast, bay, and delta areas are a major attraction for economic activities, tourism, and recreation. Therefore, these areas have major population centers with significant transportation infrastructure and lifeline routes.

The degree of vulnerability or risk to transportation infrastructure due to sea level rise depends on regional and local characteristics. Among others, impacts may include flooding of tunnels and airport runways, washouts of coastal highways and rail tracks, submersion of dock and port facilities, and a potential shift in demand for transportation. Such prospects could have strategic security, as well as transportation and economic implications. A recent study on sea level rise impacts in California estimates that areas vulnerable to future (2100) inundation currently have about \$100 billion in property values with a population of about 475,000.<sup>2</sup>

### **Marine Transportation**

California has historically experienced extreme weather-related impacts to transportation systems, including floods and landslides, disrupting State and local roadways and major rail lines. Rising sea level, besides eroding beaches, dunes, and wetlands, and increased flooding from storm surges, could also affect shipping into and out of the ports of Sacramento and Stockton with higher winter water flows in the Sacramento River. While increased siltation from storm runoff would necessitate more frequent dredging of channels across California. Harbors may suffer wave damage, additional siltation from storm runoff, and face other navigation and safety problems. Jetties and seawalls may have to be raised and strengthened to protect harbors, which support commercial shipping, recreation, and tourism.

### **Air Transportation**

Coastal airports built on wetlands are vulnerable to flooding such as the San Francisco International, Oakland International, and Santa Barbara airports. With additional inches of sea level rise, a number of critical facilities would be highly vulnerable. In the future, sea level rise, storm surges, and high tides could combine to inundate runways.

**Figure 1. 40-Inch Sea Level Rise Inundation Scenario at Bay Area Airports**



The San Francisco Bay appears to be reclaiming much of its historic reach (shoreline before human habitation and development). A sketch mapping of 40-inch sea level rise shows about 120 square miles of low areas and a number of critical facilities in the San Francisco area could be vulnerable, which would inundate the San Francisco and Oakland International Airports.<sup>3</sup>

## Road Transportation

By 2100, a 55-inch sea level rise scenario suggests that about 350 miles of major State highways could be at risk along the coastline, the delta region, and interior waterways. The most threatened environments within this corridor include deltas, low-lying coastal areas, islands, beaches, coastal wetlands, and estuaries. A breakdown of the approximately 350 centerline miles of State highways susceptible to effects of sea level rise is shown by county in Table 1. However, this list does not show the true potential impact to the State's road transportation system, which includes local streets and roads that connect these State highways to trip origins and destinations located in the vulnerable zones. The physical impacts and economic costs are still under study. Figure 2 shows an example of potential impact of sea level rise on a segment of a State highway.

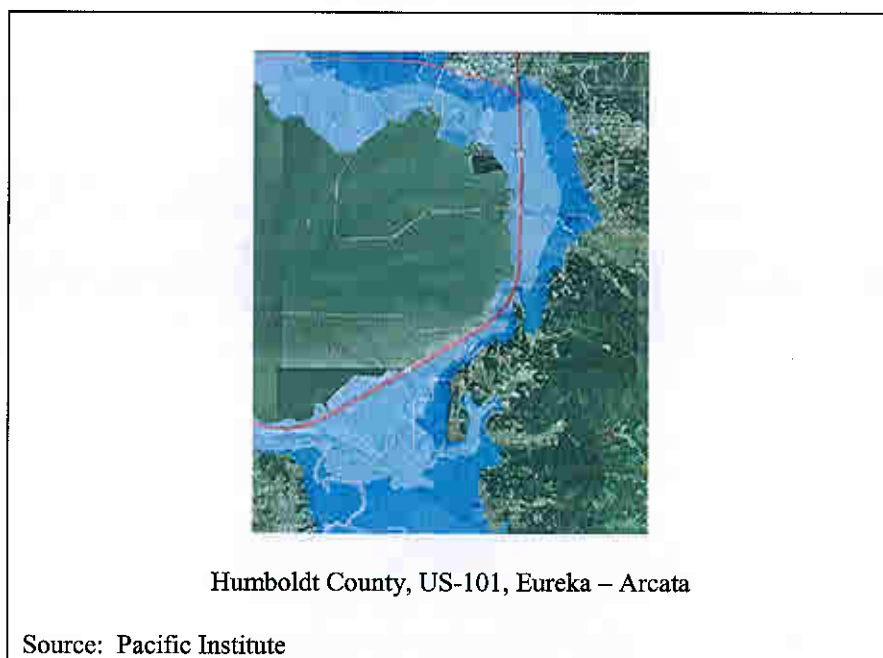
**Table 1. At-Risk State Highway Facilities Given a 55-Inch Sea Level Rise**

County	State Highway	Vulnerable Centerline Miles	County Totals
Alameda	I-880	9.3	27.0
	I-580	0.5	
	I-80	1.7	
	SR-260	1.8	
	SR-61	6.3	
	SR-77	0.4	
	SR-84	5.6	
	I-880	1.4	
Contra Costa	I-680	1.1	4.2
	I-580	3.1	
Del Norte	US-101	8.2	8.2
Humboldt	US-101	41.5	55.8
	SR-211	7.5	
	SR-255	6.8	
Los Angeles	I-710	1.2	16.3
	SR-1	10.6	
	SR-47	4.5	
Marin	I-580	3.3	38.1
	SR-1	4.9	
	SR-131	11.5	
	SR-37	4.5	
	US-101	13.9	
Mendocino	SR-1	7.9	7.9
Monterey	SR-1	17.6	26.8
	SR-156	3.7	
	SR-183	5.5	

County	State Highway	Vulnerable Centerline Miles	County Totals
Orange	I-405	2.8	26.3
	SR-1	20.7	
	SR-39	2.8	
San Diego	I-5	1.4	6.3
	SR-75	4.9	
San Francisco	I-80	0.6	1.3
	US-101	0.7	
San Luis Obispo	SR-1	7.2	7.2
Santa Barbara	US-101	3.0	3.0
Santa Clara	SR-237	4.9	10.8
	US-101	5.9	
Santa Cruz	SR-1	4.8	8.1
	SR-129	3.3	
San Mateo	SR-1	5.2	53.8
	SR-101	34.5	
	SR-114	1.1	
	SR-84	7.4	
	SR-92	5.6	
Solano	SR-29	3.4	19.6
	SR-37	16.2	
Sonoma	SR-1	3.5	15.9
	SR-116	2.4	
	SR-37	10.0	
Ventura	SR-1	11.0	11.0
Statewide Total			347.6

(I = Interstate, SR = State Route, US = U.S. Highway)

**Figure 2. Example of Potential Impact on State Route**



### **Railroads, Ports, and Freight Movement**

California's freight transportation system is comprised of a vast network of roads, airports, railroads, waterways, terminals, ports, and pipelines. Intercity rail, passenger trains, and freight trains operate on a shared track system. This vast network includes corridor segments that are located in low-lying coastal and delta areas connecting waterways to other modes for movement of goods and services. In addition to subsidence of these facilities, the strategic locations of freight facilities could become a liability in light of climate change scenarios and sea level rise increases.

The Department's Climate Action Program is collecting information to evaluate the vulnerability of primary goods movement corridors in California which will be reflected in the full Climate Adaptation Report in June 2009. The preliminary vulnerability assessment of goods movement priority corridors in California indicates that various segments of these corridors could be impacted under a 55-inch sea level rise scenario. While the impacts may be localized to several short segments, it is expected that longer stretches of the corridors listed on Table 2 would be affected with severe repercussions to the State's economy.

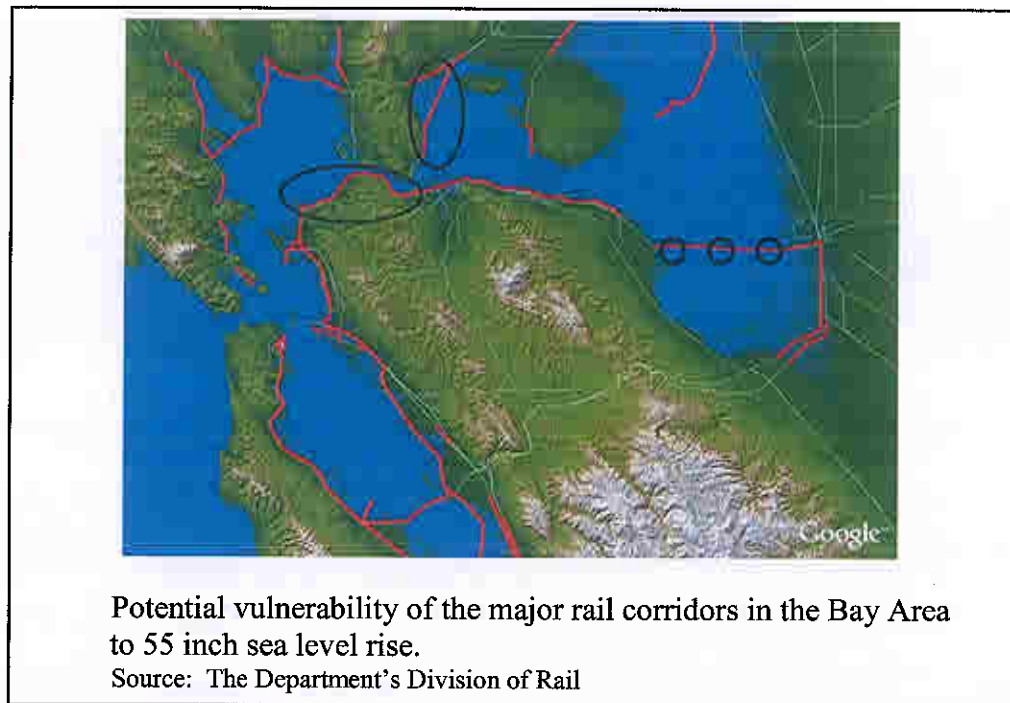
**Table 2. Priority Goods Movement Routes Affected Given a 55-Inch Sea Level Rise**

<b>County</b>	<b>Priority Trade Route Corridor</b>
Alameda	I-80 (From US-101 to the Nevada Border)
	I-880 (From I-80 to US-101)
Orange	I-405 (From I-5 to I-5)
San Diego	I-5 (From Oregon Border to Mexico Border)
San Francisco	I-80 (From US-101 to the Nevada Border)

	US-101 (From I-80 to the San Francisco Airport)
Los Angeles	I-710 (From SR-47 to I-10)

(I = Interstate, SR = State Route, US = U.S. Highway)

**Figure 3. Example of Potential Impact on the Rail System**



### **Specific Regional Impacts**

#### **The Sacramento-San Joaquin Delta**

The Sacramento-San Joaquin Delta (Delta) is a unique region relative to climate change because of the potential dire consequences across the State and indirectly on the national economy if adversely affected by climate change. The Delta, which is the largest estuary on the West Coast of the Americas and California's most important water supply, is likely to face various impacts from climate forces interacting with urban development, land use, and environmental practices. There is a significant development in low-lying areas of the Delta, where nearly 300,000 acres are below sea level.<sup>5</sup> These areas are vulnerable to sea level rise, particularly during high storm tide events. Of particular consequence to transportation, the Delta includes a significant amount of infrastructure such as roads, pipelines, power lines, aqueducts, and railroads. Risk assessment associated with this infrastructure is important to planning for adaptation in this region.

Three State highways, State Routes 4, 12, and 160, are most vulnerable to sea level rise in the Delta. In addition, a major rail line, the BNSF, traverses the Delta with lengths below sea level and protected by levees. The East Bay Municipal Utility District's aqueduct runs parallel to the rail line. Finally, since discovery of natural gas in the Delta in the 1930s, several underground storage areas are in the Delta, as well as pipelines for conveyance to final destinations. Rising sea level and higher winter water flows in the Delta are likely to cause a variety of significant problems. These problems include disruptions to sections of railroads, pipelines, and roadways within the coastal regions, effects on the transport of water from north to south, and problems with shipping into and out of the ports of Stockton and Sacramento given the potential that it will be more difficult to maintain channel depths.

**Figure 4. Example of Potential Impact on State Route**



Close proximity of coastal development to flood plains  
(North Bay near City of Vallejo)<sup>3</sup>

### **Impact on the Urban System**

The State's transportation system is highly interconnected. Urban and rural roadways are connected through the interregional State highway system and accessed through interchanges and connectors or intermodal stations. There are no trips that begin or end on a State highway or intercity rail system, including transit-dependent park and ride users. Any disruption to the State system could overload or undermine proper functioning of local streets, roads, and transit systems. This could negatively impact the movement of people, goods and services, and access to essential services such as schools and hospitals. These effects, however, depend on location. The primary and secondary infrastructures in at-risk areas that serve as evacuation routes or access would need to be identified for potential impact and will be addressed in the full adaptation report.

A study of San Francisco Bay shows 143 schools and emergency and health care facilities are at risk of a 100-year flood event by 2100 compared to 46 in 2002. An estimated 1,900 miles of roads and railways are likely to be impacted. This could further impair highway and transit operations and access to other essential services and facilities. Transit-dependent people and commuters on transit systems could be particularly impacted which in turn will have a larger impact on the overall operations of the transportation system.

Fluctuations in sea level rise may affect viability of natural resources and impact fisheries, beaches, and marshlands, as well as patterns of development in certain coastal areas. This could mean shifts in demand for new roads, rail lines, and other services and also a need for significant

investments in transportation and other infrastructure.

## **Conclusion**

Because the signs of climate change are already visible, the State must prepare for the potential impact that is expected. A sound and resilient transportation system is vital to California's social and economic future. Investments in transportation are substantial and result in long-lasting infrastructure. It is clear that any disruption to this complex system will have immediate impacts. How well the system adapts to climate change and sea level rise is critical. At the same time, there is a need for economic perspective in adaptation policy to ensure cost-effective and proportionate responses and consideration of the wider economic costs and benefits of adaptation.

This report provides a preliminary assessment of transportation system vulnerability to sea level rise. BTH and the Department are developing a more comprehensive adaptation report that will include other anticipated climate variations, outline a series of program-specific strategies, and a process to integrate consideration of climate variations into State transportation investment decision-making. This adaptation report will be available in June 2009.

The Department will develop provisions for investments critical to safety, operations, and maintenance of the transportation system and economy of the State. EO S-13-08 on sea level rise recognizes that investment in transportation safety, maintenance, and operational improvements is critical to public safety and the economy of the State, and that mobility is the key to socioeconomic activity and quality of life. Therefore, investments essential to transportation operations and public safety and the economy of the State will continue to receive priority attention as adaptive strategies are developed.

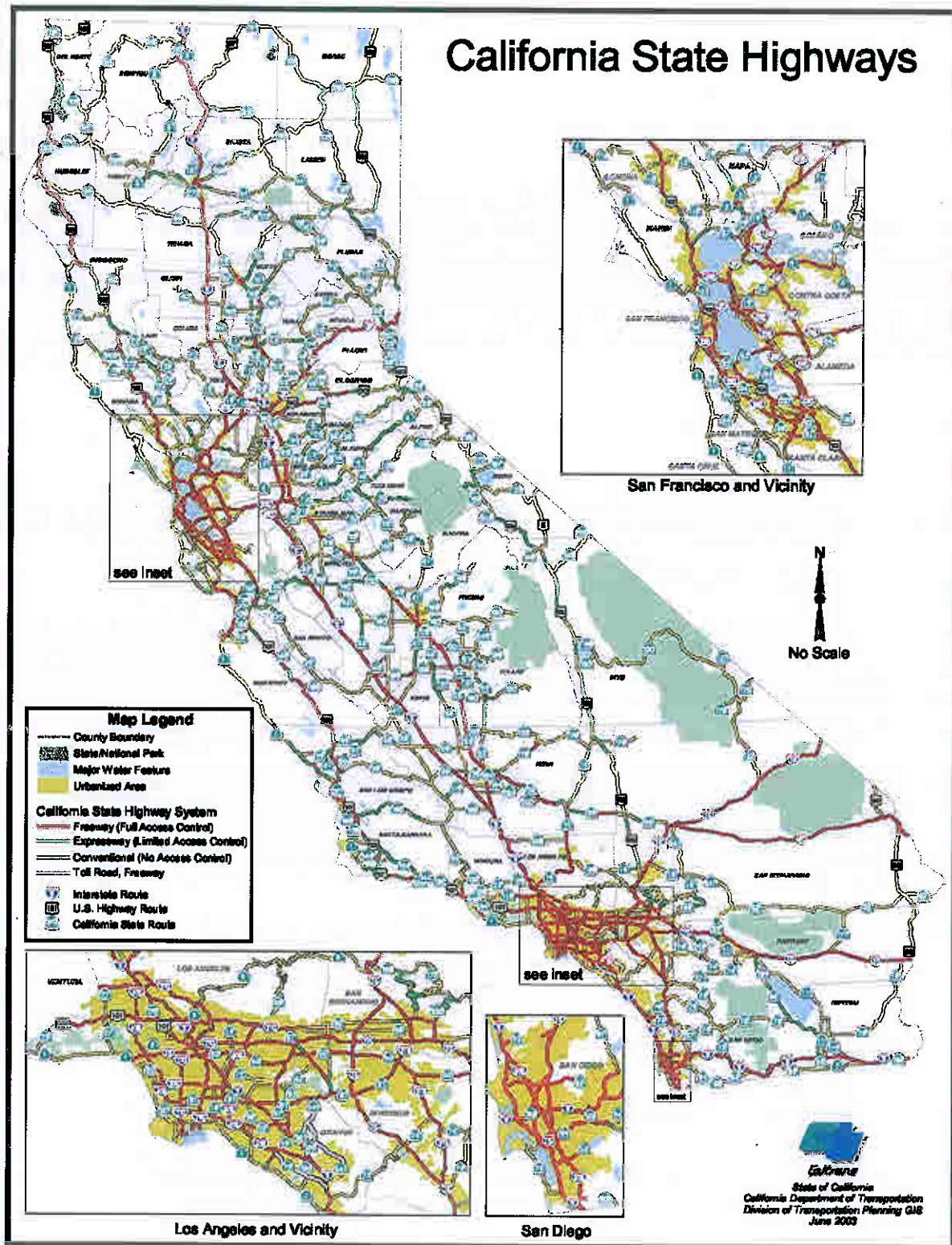
Finally, BTH and the department are also adapting to better respond to the advancing science and policy implications of climate change. This is a basic step that will ensure appropriate attention is given to issues related to climate change while continuing to focus on the respective missions. It is expected that this organizational adjustment will mature to allow the mainstreaming of anticipated mitigation and adaptive strategies.

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## **References**

1. Kahrl F, Roland-Host D. California Climate Risk and Response, University of California at Berkeley. November 2008, p. 3.
2. Gleick P. The Cost of Adaptation to Sea Level Rise Along the California Coast and in the San Francisco Bay. California Climate Change Center. October 2008, pp. 42-47.
3. Bay Area Conservation Development Council.
4. Graham S, Segall J. Working Group: Adaptation to Climate Change. July 2008.
5. Roos M. Sea Level Rise: What is the Water Engineer to do with all those Projections? Unpublished draft. October 2008, p. 4.
6. Delta Vision Blue Ribbon Task Force. 2007.

## Attachment I



## Attachment II

### Priority Regions and Corridors in California

